

N92-11096

A CERMET FUEL REACTOR FOR NUCLEAR THERMAL PROPULSION

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I want to talk to you about the cermet fuel reactor. I will discuss the work that was done in the 1960s. Very little work has been done since that time.

The cermet reactor work came out of both the ROVER program and the aircraft nuclear propulsion program (Figure 1). The 710 program was conducted at General Electric in Cincinnati while the nuclear rocket program was conducted by ANL; these programs were complementary. They both used the same kinds of fuel materials and both supported the same kinds of goals and objectives. The goals were to develop systems that could be used for nuclear rocket propulsion as well as closed-cycle propulsion system designs for ship propulsion, space nuclear propulsion, and other propulsion systems.

Part of that work involved fuel materials fabrication. There were reactor physics experiments, and there was an engineering analysis, and fuel test program. What I would like to do is give you a little background on both the 710 program at GE, and then the ANL program so you will have an understanding of the work that has been accomplished so far.

At GE there were a number of different facets to the program (Figure 2). The 710 program goal was a 10,000 hour continuous operation design life for the closed cycle designs. They also had goals for a nuclear rocket. Design and control analyses were performed and fuel materials development was performed in the laboratories along with some fuel testing in reactors.

Fuel materials compatibility testing and clad compatibility testing were performed. A number of full-size fuel elements were fabricated and then tested up to 12,000 hours of operation. There were in-reactor radiation tests, and finally, critical experiments at GE.

At ANL, (Figure 3) the program focused on rocket propulsion areas and there were two specific designs that were prepared during that time period. For the 2,000 megawatt reference engine, cycle studies and core analysis studies and design studies were performed. Fuel materials work was performed in the laboratory for tungsten cermets with uranium oxide fuel. The assemblies were clad with tungsten. ANL developed a stabilized UO_2 fuel and investigated several different cladding techniques. ANL fabricated fuel elements and tested them statically as well as dynamically and then they also performed critical experiments.

Figure 4 is a comparison of the requirements for the NASA workshop here versus the ANL study which was done in 1960. The engine thrust was around 100,000 pounds. It was a single engine. Reactor power was 2,000 megawatts thermal. It was operating in a single mode. The engine thrust-to-weight turned out to be a factor of five. Specific impulse was 832 seconds. The nozzle expansion ratio was 50-to-1 as opposed to 100-to-1.

The system was designed for about ten hours of operation. It could withstand multiple startups and basically could meet the other goals shown in Figure 4.

Figure 5 illustrates the engine itself. It has a bleed cycle where the coolant comes from the source and then flows down through the nozzle, cooling the nozzle, and then flows through the reflector control drum segments and back into the entrance of the reactor and through the reactor.

Figure 6 shows some of the characteristics of the engine. This is a fast reactor; 2,000 megawatts thermal. It provides 832 seconds specific impulse, 100,000 pounds thrust, and operating time is about ten hours. It can restart up to about 40 cycles and uses liquid hydrogen as propellant with a flow rate of 120 pounds per second. The fuel was composed of 60 percent UO_2 and 40 percent by volume of tungsten, fully enriched fuel. The core itself is about 34 inches long and about 24 inches in diameter. There were 163 hexagonal shaped elements, 1.87 inches across the flats.

Figure 7 shows the core design with hexagonal shaped fuel elements that are suspended from a plate at the entrance of the reactor. There are 163 of these elements, which use a rather simple design, with only one support point at the inlet end. The reactor is controlled by beryllium control drums (Figure 7)

Figure 8 shows the fuel element. It consists of a hexagonal-shaped tungsten matrix with the fuel particles blended in with the tungsten and then compressed. There are coolant holes provided that allow the coolant to flow through the matrix.

The cermet is clad with a tungsten/rhenium cladding on the outside surface and also the inside of the tubes. This particular design uses a fuel segment region with beryllium oxide reflector region and an inlet end fuel support point.

The operating condition for the engine at full power produces an Isp of 832 seconds with 100,000 pounds thrust. The reactor outlet temperature is about 4,500 degrees Rankine.

One of the major program tasks involved developing fuel fabrication techniques for the cermet reactor. Figure 9 shows the process that was developed, basically starting with fuel compacts, which contained a dispersion of UO_2 fuel within a tungsten matrix. The compacts are combined with header plates that are drilled.

The fuel compacts were stacked. Then the tubes were slid through the fuel compacts

and into the header. The header ends were welded. An outer hexagonal cladding unit was prepared and installed over the assembly. The cladding was welded to the header. Then the entire system was bonded so that the outer cladding and inner cladding would be bonded to the tungsten cermet. (Figure 10). These elements were very successful, very high quality, providing a very high-integrity fuel design.

Figure 11 shows an example of a fuel element that was built at ANL. It has 331 flow passages and it is designed for the nuclear rocket. It is an example of what can be done with the cermet fuel.

At GE, the fuel was tested extensively, both in-core and out-of-core as shown in Figure 12. 60 percent UO_2 and 40 percent tungsten cermet clad with the tungsten/rhenium cladding was used. The program was designed to demonstrate structural integrity of the fuel assemblies, high temperature performance, retention of fission products, compatibility of fuels and materials at high temperatures, dimensional stability and development of the manufacturing process.

All of these goals were achieved under the 710 program. Most of the testing was done at lower temperatures than we would expect to see for the nuclear rocket program, but ANL did additional tests on similar kinds of elements at higher temperatures.

There were some tests run at 2800 K, ex-pile, and these were run steady-state as well as at thermal cycles. The results demonstrated that the fuel was very forgiving under many thermal cycles. There were no breeches in the cladding.

Figure 13 shows the fuel development test program at ANL. They started off with some very simple wafers where they developed various coatings and claddings. In some cases the elements were clad, and in other cases they were vapor-coated with tungsten or tungsten uranium. They also developed a technique of coating the fuel particles before they were put into the matrix and then they would be clad, so you have basically a double barrier (Figure 14).

A VOICE: The particle would be coated with tungsten?

MR. KRUGER: Yes, the UO_2 coated with tungsten which was then clad.

These elements were run in a high temperature furnace (Figure 13). They were all run at about 2,500 degrees centigrade. They were then evaluated. The seven hole samples were fabricated and run through a temperature cycle furnace and finally through a small flowing loop hydrogen test. The 331 hole sample was manufactured but they never did get to the testing program because the program was terminated prior to the testing.

Figure 15 shows work that was done by ANL to develop a stabilized version of the UO_2 ; What they found was by adding a certain percentage of gadolinium to the matrix, they

could prevent loss of fuel from the UO_2 . These tests here were run for cases where there was no cladding on the fuel sample. You can see they were run at 2,500 C up to maybe a hundred cycles or more. Very good stability was demonstrated under those conditions (Figure 16).

The transient test was run in the TREAT facility with the cermet fuel (Figure 17). These were run with very high surface temperatures up to 2,750 temperatures centigrade, and also at very high rates of temperature change, up to 4,500, 6,000 degrees C per second. Because of the limitation on the facility, these were not maintained at temperature for very long, but they were run for a number of thermal cycles. This gave very encouraging results that the cermet fuel can take very severe transients and not fail; no failures were noted under these tests.

The cermet fuel was also being considered for use in a Brayton cycle with operation up to a year, and a number of tests were run in-reactor. Figure 18 shows the results of those test programs. The cermet fuel reached a burn-up of about half a percent with no fission product release. If accommodation was provided in the fuel matrix for fission products, even higher burn-ups could be achieved.

Figure 19 indicates the technology development for cermet fuel. We need to reinstate the cermet fuel manufacturing and qualification program, and there are several key areas of design and development testing required. First, we need to establish the fuel form that will be required through some system analyses or system development studies. Once that has been established, we will propose fabricating some small fuel samples and then verifying the material compatibility at temperature with the fuel stabilizer and the cladding. Then we would run small samples at temperature, conduct some irradiation, and run transient tests on the reference fuel form to demonstrate its capability. Finally, we would fabricate full-size elements and run those in full-flow transient tests to demonstrate stability needed to withstand the testing environment. This would then lead to a full-size reactor qualification test (ground test).

Most of the materials work has been accomplished as a result of the large data base developed for materials in the 1960s for tungsten and tungsten/rhenium alloys (Figure 20). There will be some additional materials testing that will be required and we would suggest that rhenium be considered as a possible candidate for fuel cladding because of its weldability.

For the reactor component development test, we would take maximum advantage of NERVA technology (Figure 21). We suggest that ROVER technology be used for reflector control drive development testing because similar drive systems are used. Of course, some reactor flow hydraulic testing is needed. The core mechanical support design needs to be verified and tested. The preheat zone just outside the reactor core may need testing. A review of data from the existing critical assemblies is needed to determine if any additional critical tests would be needed.

We believe that a full system ground test is needed in order to qualify the system for flight. (Figure 22). Of course, stringent safety precautions are going to be needed to prevent environmental releases during the ground test. One of the features of the cermet fuel is its inherent capability to retain fission products. It offers a very positive containment with essentially a zero-release to the environment. The ground test requirements may not be quite as severe for the cermet fuel as for other concepts.

Figure 23 presents a reasonable, although fairly aggressive schedule. It shows about nine years from the time of start until the time to launch. It also shows the flight option being initiated in parallel with the ground test. The key activities that need to be started right away would be mission studies and concept definition studies to define the reactor system and the fuel form. That information then would be fed down into development testing for the fuel.

At the same time, facility studies must be initiated so that the facility preparation could begin, leading to the ground test. Parallel with other activities we would have technology support as well as safety analyses and a rather rigorous safety program.

We need to take advantage of the technology that already exists. Both the NERVA and ROVER system experience can be applied to the cermet fuel reactor. Test facilities, support systems, the effluent cleanup systems, test operations, and all lessons learned could certainly be applied to the cermet reactor.

Safety is a paramount consideration (Figure 24). The cermet fuel offers some very definite safety advantages. It's a high-strength, very rugged fuel form that can withstand thermal transients and repeated rapid thermal cycles. It offers a positive way to retain fission products with essentially zero release, either on the ground or in space. It also provides very high strength for safe reentry and burial in the event there would be a launch abort accident. The tungsten/rhenium materials provide inherent safety in the event of a water immersion accident.

In conclusion, the cermet fuel work conducted in the 1960's has demonstrated that we can have excellent thermal and mechanical performance. Thousands of hours of testing were performed on the cermet fuel, both at GE and ANL, including very rapid transients and some radiation performance history. We conclude that there are no feasibility issues with cermet fuel. What is needed is reactivation of existing technology and qualification testing of a specific fuel form. We also believe that this can be done at minimum development risk.

A VOICE: One, you didn't mention the mass. Two, you didn't discuss the limitations of the fuel form.

MR. KRUGER: We haven't really optimized the mass, because what I have presented to you here is a study that was done by ANL back in the 1960s. The thrust-to-mass ratio

is approximately five, which gives you a ballpark number. The limitation on fuel is temperature.

We believe that the fuel temperature can approach 3,000 K. The maximum fuel temperature was running around 2,700-2,800 degrees kelvin in these studies; the melting point of UO_2

A VOICE: What is the fuel analysis lifetime?

MR. KRUGER: It depends on the temperature you operate at, of course, but under the case I showed here, it could be hundreds of hours.

A VOICE: What is your base design fuel loading?

MR. KRUGER: How much UO_2 ? 635 kilograms UO_2 .

A VOICE: If the UO_2 is contained within the tungsten, why is the UO_2 melting a limiting criteria?

MR. KRUGER: It wouldn't necessarily have to be, if we could assure it could be contained in the tungsten/clad matrix.

A VOICE: What about the possibility of a UO_2 -thorium mixture. It has a much higher melting point.

MR. KRUGER: Yes, that's true. UO_2 -thorium has a much higher melting point and that could be a possible alternative. That was being considered in the 710 program at GE but had not been fully tested or developed.

A VOICE: What is the temperature limit on the operation if we simply consider the tungsten?

MR. KRUGER: Tungsten could go to much, much higher temperatures. I don't have a limit on that, but tungsten could go to much higher temperatures.

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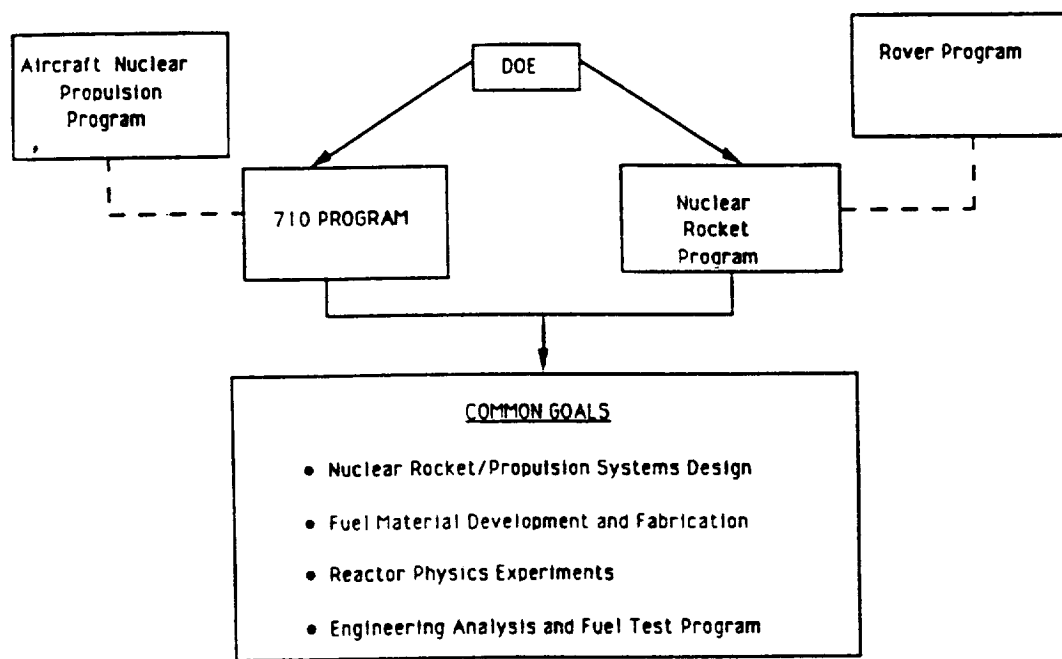
G.B. Kruger

Cermet Fuel Reactor Presentation

1. "Nuclear Rocket Program Terminal Report" ANL-7236, June 30, 1966, Argonne National Laboratory
2. "710 High Temperature Gas Reactor Program Summary Report" GEMP-600 (six volumes) Nuclear Technology Department, Nuclear Energy Division, General Electric, Cincinnati, Ohio.



DIRECT NUCLEAR PROPULSION TECHNOLOGY DEVELOPMENT



*Cermet Fuel Technology and Propulsion System Development
Took Place During the Period 1962-1968*

Figure 1



CERMET FUEL PROPULSION PROGRAMS IN THE 1960'S

710 PROGRAM AT GE

- Reactor Systems Design & Analysis
 - Liquid Metal
 - He
 - H₂
- 10,000 Hr Continuous Operation Design Life
- Nuclear Rocket
 - 30,000 - 200,000 lb Thrust
 - 10 Hr Full Power
 - 100-200 Restart
 - 850 - 870 Sec Specific Impulse
- Control Analysis
- Fuel + Materials Development
 - UO₂
 - W-Cermet
 - Mo Cermet
 - Clad
 - W-Re
 - W-Mo-Re
 - T-111
 - Mo-Re
- Fuel/Materials Compatibility
- Fuel/Clad Compatibility at 4700°F (2867K)
- Fuel Element Fabrication
 - Process Development
 - 19 and 37 hole full sized elements
- Fuel Element Testing
 - Non Nuclear Static/Dynamic
 - 3000°F (1922K)
 - Helium/Neon
 - Up to 12,000 hrs
- In-Reactor Irradiation Tests
 - Equivalent to 1 year operation
 - 2000 F (1367K)
 - Up to 5000 hrs in Reactor
- Critical Experiments
 - 9 Critical Experiment Configurations

Figure 2



CERMET FUEL PROPULSION PROGRAMS IN THE 1960'S

NUCLEAR ROCKET PROGRAM AT ANL

- Rocket Propulsion Design and Analysis
 - 2000 MW Reference Engine
 - 200 MW Alternate Engine
- Elements
 - Cycle Studies
 - Core Design and Analysis
 - Control Studies
- Fuel and Materials Development
 - Fabrication Process Development
 - Fuel/Materials compatibility
 - UO₂
 - W Cermet
- Assemblies
 - Clad
 - W-Re
 - Stabilized UO₂
 - Pressure Bonded Cladding vs Vapor Deposited cladding
 - Material Property Testing
- Fuel Element Fabrication
 - Vapor Deposited Cladding and Pressure Bonded Full Size
- Fuel Element Testing
 - Non Nuclear Static/Dynamic
 - Up to 2600°C (2873K)
 - Reactor Dynamic Tests - Treat
 - Up to 2750°C (3023K)
 - 10,000° C/sec Transients
- Critical Experiments
 - Eight Critical Experiment

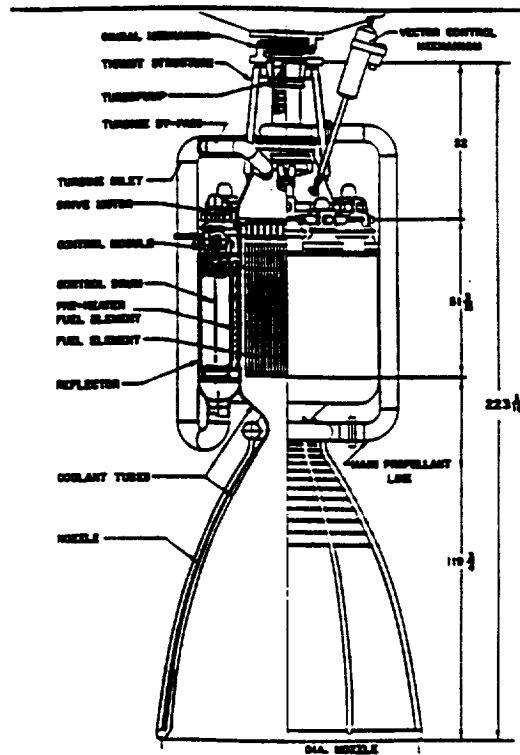


Figure 3

NUCLEAR THERMAL PROPULSION - REQUIREMENTS

REQUIREMENT PARAMETER:	UNITS:	BASELINE DESIGN - MANNED MARS	VARIATION FROM BASELINE:	CERMET CORE NTR CONCEPT (ANL STUDY)	CERMET CORE NTR VARIATION FROM BASELINE
Engine Availability	Year	2015	200-2017	Meet Schedule	Meet Schedule
Thrust Per Engine	klb(t)	75	25-250	100K	Design Accommodates Broad Range of Engine Thrust Requirements
Number of Engines	Number	1	Multiple	Single	Engine Concept is Feasible
Reactor Power (Thermal)	MW(t)	1500	600-5000	2000	No Limitation on Power Range
Dual Mode-Low Electric Power	kWe	0	25-50	Single Mode	Can Be Designed For Dual Mode High/Low Electric Power
Dual Mode-High Electric Power	MWe	0	1-5	Single Mode	
Engine Thrust/Weight	klb(F)/klb(m)	4	3-10	-5	Falls Within Range
Specific Impulse	Seconds	850	850-1200	832	Current Studies Indicate Range of 81 800-900
Nozzle Expansion Ratio	Ratio	100:1	100:1-500:1	50:1	Can Accommodate Greater Expansion Ratio
Propulsion Operating Time/Mission	Minutes	120	43-120	10 Hrs	Minutes to 10's - 100's of hours Can be Accommodated
Number of missions	Number	1	1-5	1	Can Accommodate Several Missions
Number of Startup Cycles/Lifetime	Number	6	1-30	Multiple	Can Accommodate Many Restart Cycle
Average Mission Duration	Days	434	270-600	Can Meet	No Limitations on Mission Duration
Reliability	Number	0.995	0.995-0.975	High Reliability	System Simplicity & High Strength of Cermet Fuel Provides High Reliability
Deployment Orbit	Kilometers	407	407-700	Can Meet	Can Meet Alternate Orbits
Maximum Crew Radiation Limits from Reactor Source	REM/Yr	5	0-5	Shielding Required	Optimized Shielding For Mission and Compact Core

Figure 4



NUCLEAR THERMAL PROPULSION ENGINE
CERMET CORE 2000 Mwt

Figure 5



CERMET REACTOR FOR 2000 Mwt PROPULSION ENGINE

REACTOR ENGINE CHARACTERISTICS

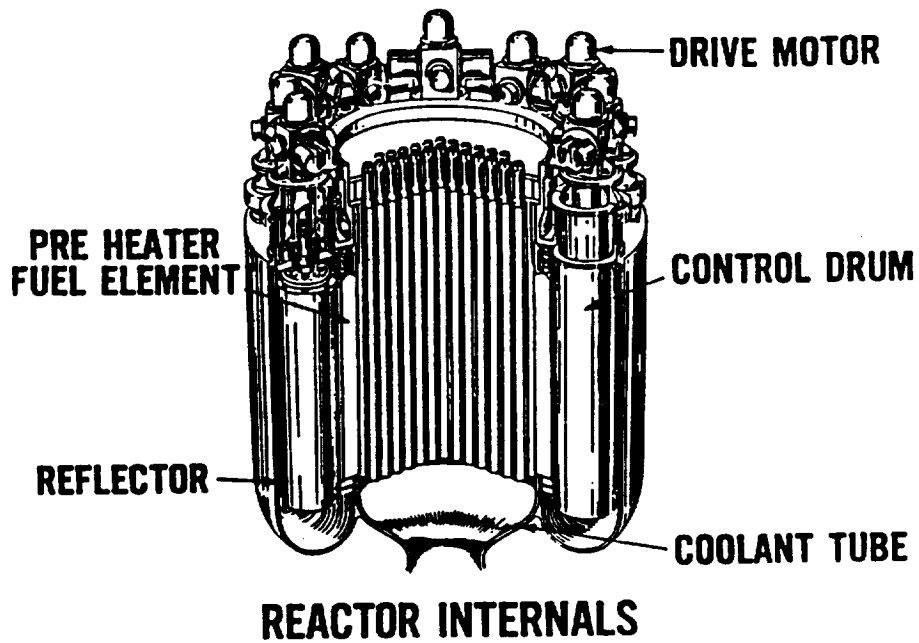
Reactor Type	Fast
Reactor Power	2000 Mwt
Specific Impulse	832 Sec
Thrust	~100,000 lb
Operating Time	Up to 10 hrs
Restart Capability	Up to 40
Propellant	Liquid Hydrogen
Flow Rate	120 lb/Sec

FUEL

COMPOSITION	60 V ² O ₅
MATRIX	40 V/W
U ₂₃₅ ENRICHMENT	93%

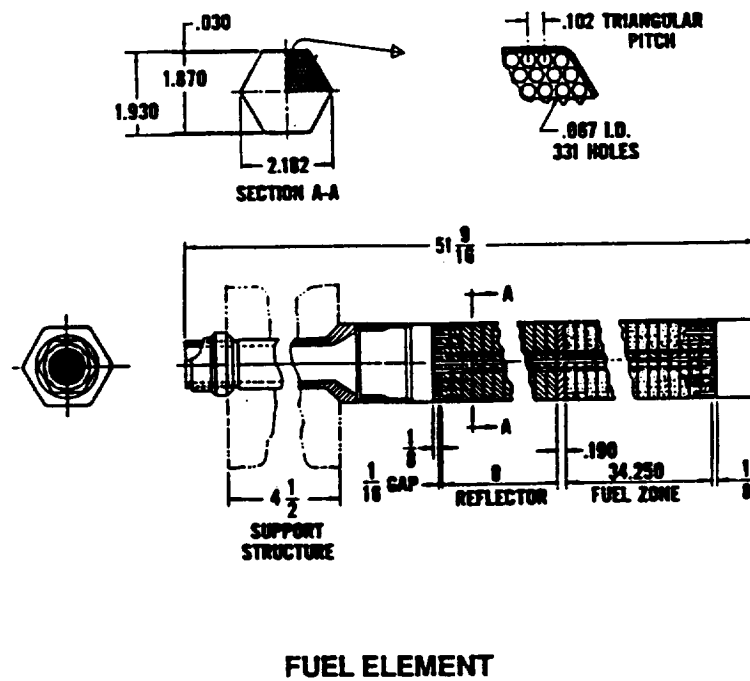
FUEL ELEMENT

Length Active	34.25 in
Across Flats	1.87 in
No Assemblies	163
Fuel Clad	W-25 Re
Peak Fuel Temp	4912°R (2728K)



**CERMET REACTOR CONCEPT FOR
2000 Mwt PROPULSION ENGINE**

Figure 7





FACE-GROUND HEADER BLANK

- Ultrasonic inspect.
- Cut rough hex
- Surface grind - opposite faces flat and parallel within 0.0002 inch

DRILLED HEADER

- C-2 carbide drills
- Torque controlled feed rate
- 19 holes
- Diameter tolerance: ± 0.001 inch
- Position tolerance: 0.001 inch radius from true position

EMBOSSED HEADER

- Electric discharge machine (EDM)
- Gentrade 10 (graphite) electrode
- Chemically clean
- Hydrogen clean
- Vacuum clean (10^{-5} torr)

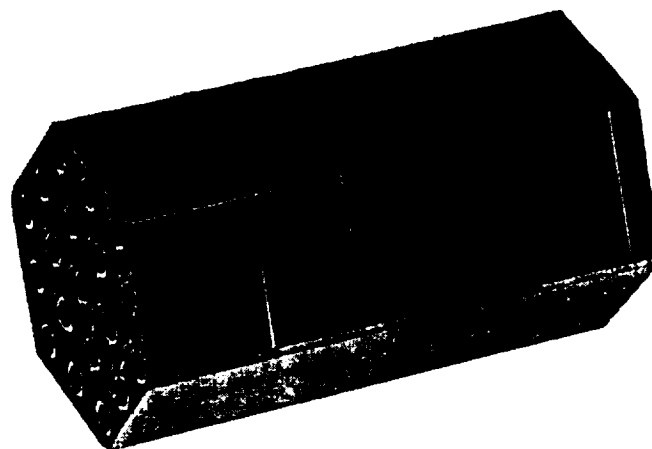
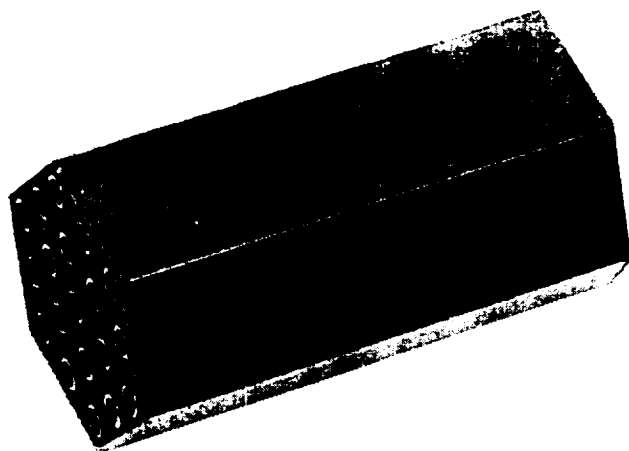
COOLANT TUBES

- Eddy current inspect
- Cut to rough length
- Grind to final length
- Re-eddy current inspect
- Chemically clean
- Vacuum clean (10^{-5} torr)

HEXAGONAL OUTER CLADDING

- Ultrasonic inspect
- Shear and grind to width
- Form to half-hexes and grind edges
- Chem. clean and heat treat
- Electron beam weld seams and X-ray
- Isostatically press to size
- Grind to length and leak check
- Chem. and vacuum heat clean

Figure 9



AS-ASSEMBLED AND SEALED

- Stack fueled segments
- Insert tubes
- Insert segments into hexagonal cladding
- Install headers
- Inspect
- Electron-beam weld hexagonal cladding and tubes to headers
- Leak check by helium mass spectrometer

AS HOT-GAS PRESSURE BONDED

- Load into bonding apparatus
- Pressurize, purge, and backfill with inert atmosphere
- Bond at 3180°F and 10,000 psig in He for 1.5 hours
- Leak check by helium mass spectrometer
- Bond checks: OD cladding by resonance frequency and pulse echo; ID cladding by through transmission
- Dimensions, weight, volume approx. 96-97% theoretical density
O/U ratio - 2.00

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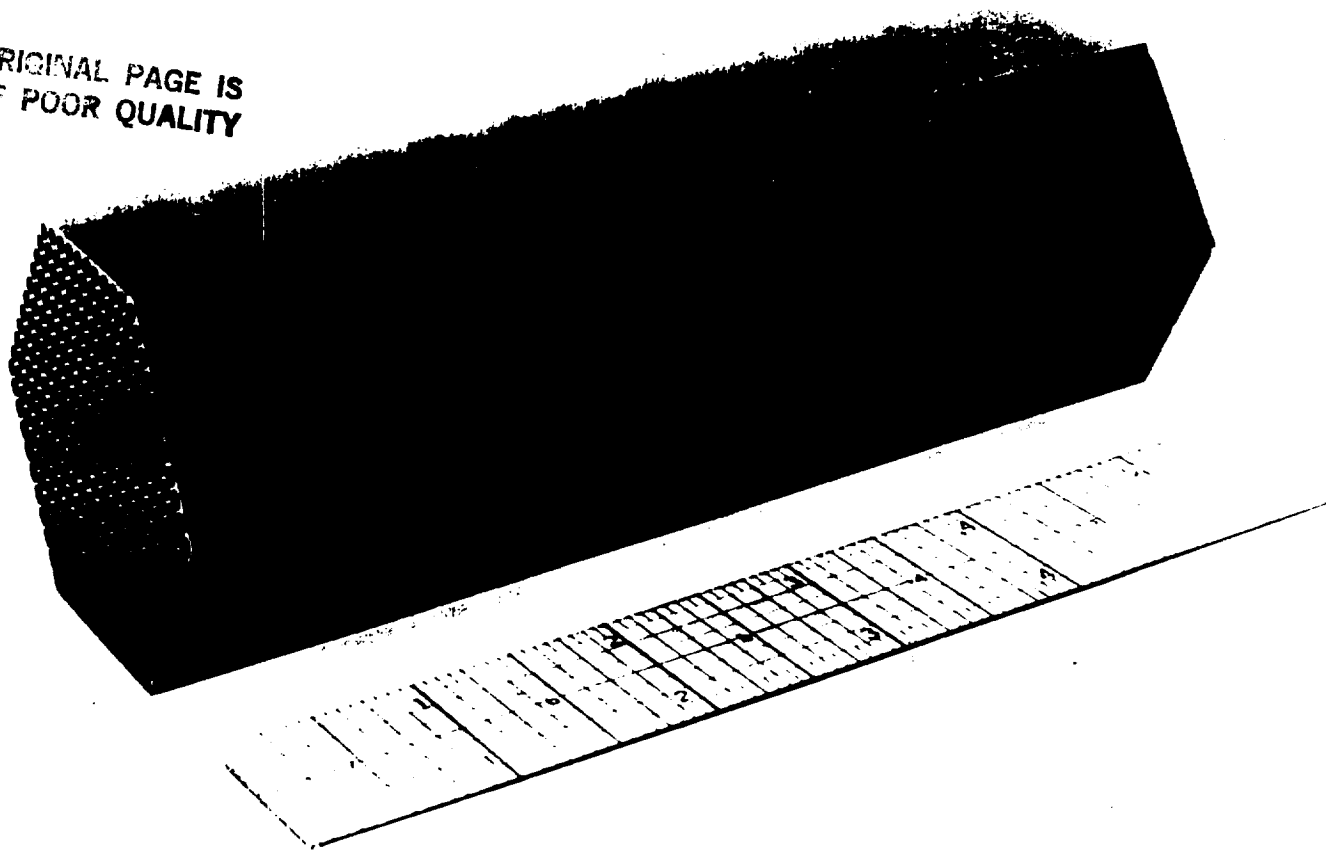
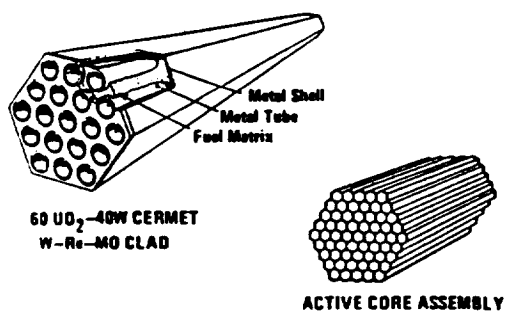


Figure 11

Fuel Element Sample, Large Nuclear Rocket



RESULTS OF CERMET FUEL TESTING - 710 Program

- STRUCTURAL INTEGRITY OF FUEL ELEMENT DEMONSTRATED UNDER STEADY STATE & TRANSIENTS
- HIGH TEMPERATURE PERFORMANCE ACHIEVED
- RETENTION OF FISSION PRODUCTS ACHIEVED
- FUEL AND MATERIALS COMPATIBILITY DEMONSTRATED
- DIMENSIONAL STABILITY DEMONSTRATED
- MANUFACTURING PROCESS DEVELOPMENT ACHIEVED

EXTENSIVE FUEL TESTING DATA BASE

HIGH TEMPERATURE EX-PILE STATIC/DYNAMIC TESTS

- 28 TEST ELEMENTS
- UP TO 90 THERMAL CYCLE RUNS/ ELEMENT BETWEEN 530K AND 1920K
- UP TO 12,000 HRS/ELEMENT

VERY HIGH TEMPERATURE DYNAMIC EX-PILE TESTS

- TO 2800K TEMPERATURE
- 193 THERMAL CYCLE RUNS
- 49 HRS TEST DURATION

BURST TRANSIENT TESTS IN TREAT

- SUCCESSIVE BURSTS TO 3020K WITH COOLDOWN
- EIGHT SPECIMENS
- UP TO 6 CYCLES EACH

HIGH TEMPERATURE IN-PILE QUALIFICATION TESTS - 710 PROGRAM

- 21 TEST ELEMENTS
- UP TO 1890K
- 10,000 HRS MAX. DURATION
- 0.5 AT % BU ACHIEVED - Porosity Requirements For Long Life Established
- UP TO 80 THERMAL CYCLES/ELEMENT

88-206 01



FUEL DEVELOPMENT TEST SEQUENCE

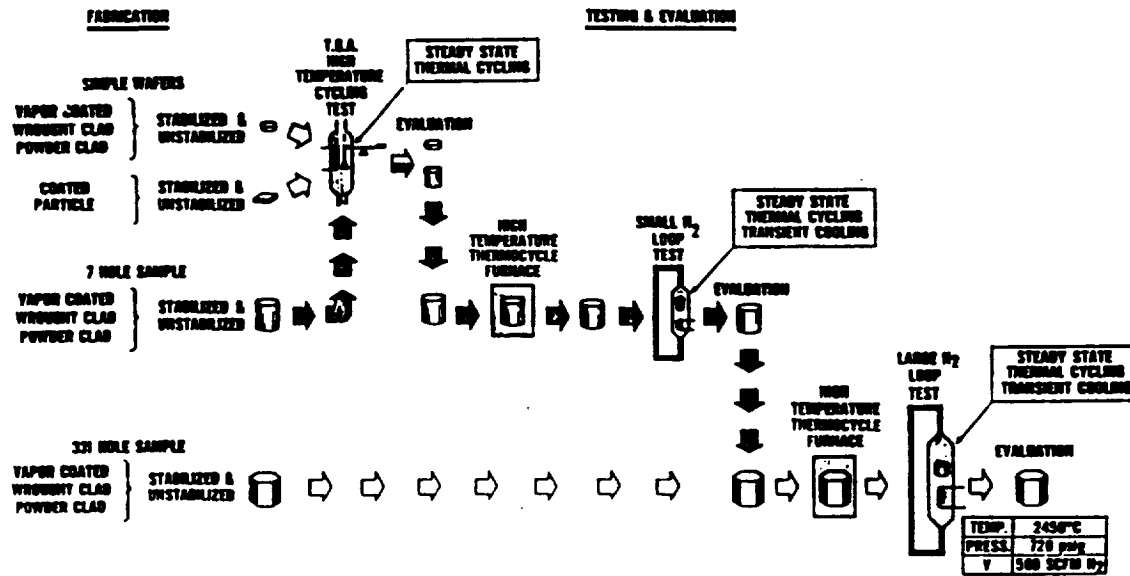
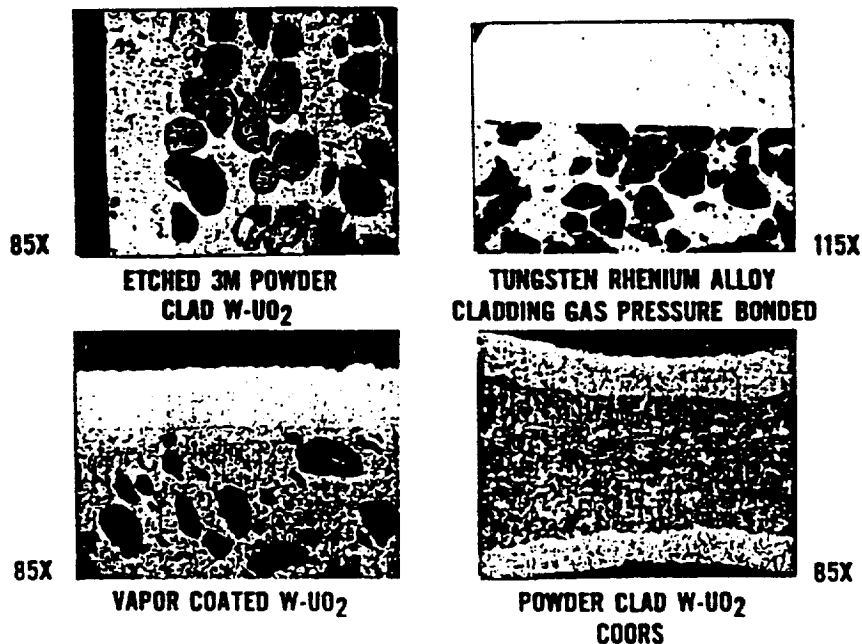


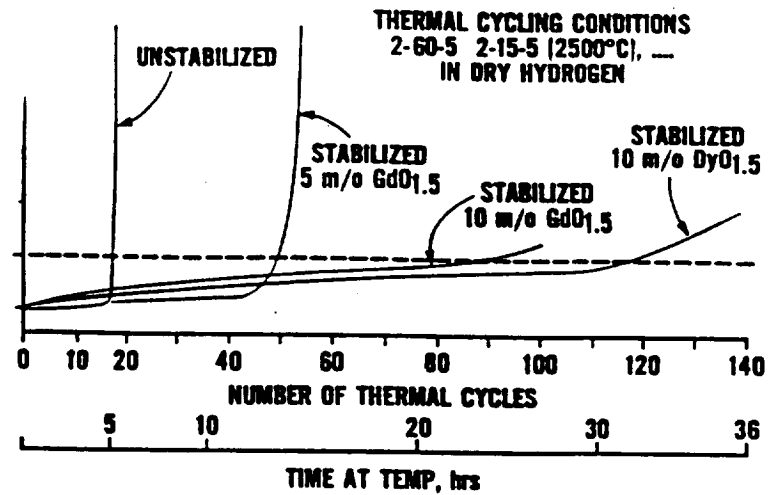
Figure 13

VARIOUS CLADDING TECHNIQUES



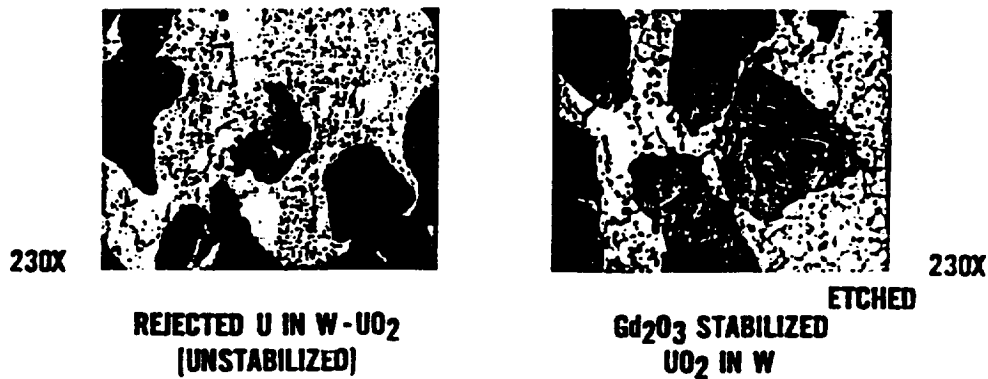
CERMET FUEL THERMAL CYCLING AT 2500°C

FUEL LOSS COMPARISON



Tests of Cermet Fuel with Ga Stabilizer Demonstrate Stability at Temperature and with Thermal Cycling

Figure 15



EFFECT OF Gd₂O₃ STABILIZER



TRANSIENT TREAT TEST RESULTS

SAMPLE NO.	TRANSIENT DURATION (SEC)	REACTOR INTEGRATED (MW-SEC)	MAXIMUM RECORDED SURFACE (°C/SEC)	MAXIMUM RECORDED SURFACE TEMPERATURE (°C)
1	0.43	164	1,700	800
1	0.3	284	3,900	1,460
2	0.3	377	5,600	1,790
3	0.2	487	8,000	2,200
4	2.1(A)	332	800	1,460
5	0.2	540	2,000	2,600
6	3.0(B)	495	1,400	2,050
7(B)	0.2	523	4,500	2,750
8(C)	0.2	532	6,000	2,750

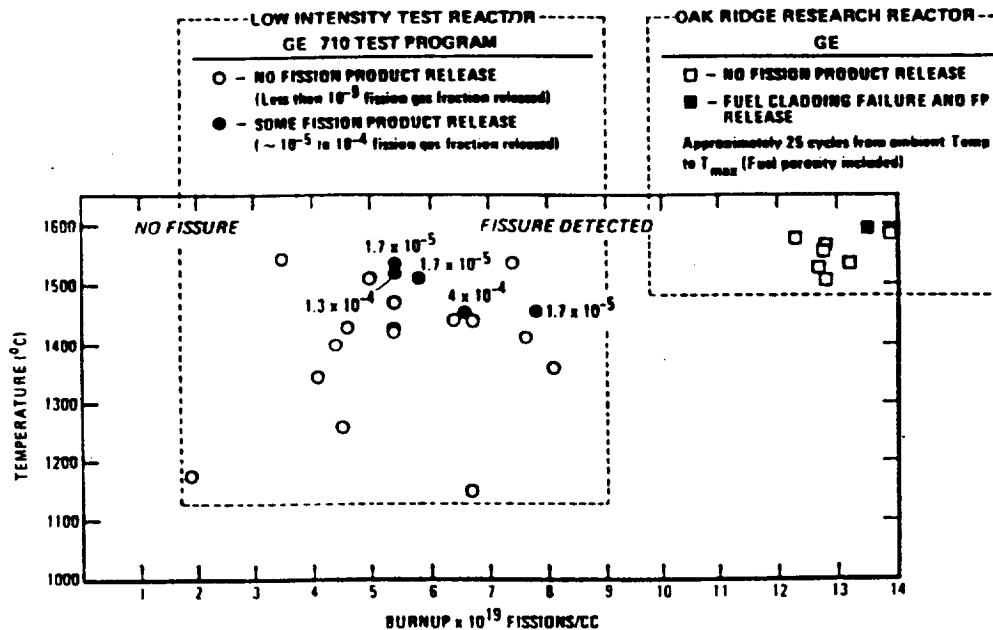
- (A) "FLAT TOP" TRANSIENT
 (B) SAMPLE GIVEN TWO ADDITIONAL TRANSIENTS OF SAME SEVERITY
 (C) SAMPLE GIVEN FIVE ADDITIONAL TRANSIENTS OF SAME SEVERITY

NO FUEL FAILURES WHEN SUBJECTED
TO SEVERE THERMAL TRANSIENTS

Figure 17



GE CERMET FUEL TEST PROGRAM BRAYTON CYCLE QUALIFICATION



ALL THERMAL CYCLING PINS THERMALLY CYCLED FROM 0.5 T_{max} to T_{max} DURING IRRADIATIONS - CYCLES RANGED FROM 33 to 60

Figure 18



CERMET FUEL KEY TECHNOLOGY DEVELOPMENT

- Reinststate Cermet Fuel Manufacturing Technology and Qualify the Specific Fuel Form for NTP
- Key Areas of Design/Development and Qualification Testing
 - Establish Fuel Form Requirements Through System Studies
 - Fabricate Small Fuel Samples for Testing and Select Reference Fuel Form
 - .. Verify Material Compatibility
 - .. Verify Fuel Stabilizer
 - .. Verify Cladding Approach
 - Conduct Irradiation/Transient Testing on Reference Fuel Form
 - Fabricate Full Size Fuel Assemblies
 - Perform Full Flow Transient Tests of Full Size Assemblies
- Conduct a Full Size Reactor Qualification Test (Ground Test)

Figure 19

MATERIALS DEVELOPMENT TASKS:

- The Fundamental Materials Database Was Developed for W, W/Re Materials in the 1960's
- Limited Materials Property Testing May be Required to Verify the Materials Database
- Rhenium Should be Considered a Possible Candidate for the Fuel Cermet Cladding to Provide Improved Weldability of the Clad Material

Figure 20

REACTOR COMPONENT DEVELOPMENT TASKS

- Utilize Modified NERVA Technology for Reflector Control Drive Development and Testing
- Reactor Hydraulic Flow Testing
- Reactor Core Mechanical Support Development and Testing
- Reactor Pre-Heat Zone Fuel Element Thermal/Hydraulic Testing
- Review Data from Existing Critical Assemblies to Determine if Additional Criticals are Required

Figure 21

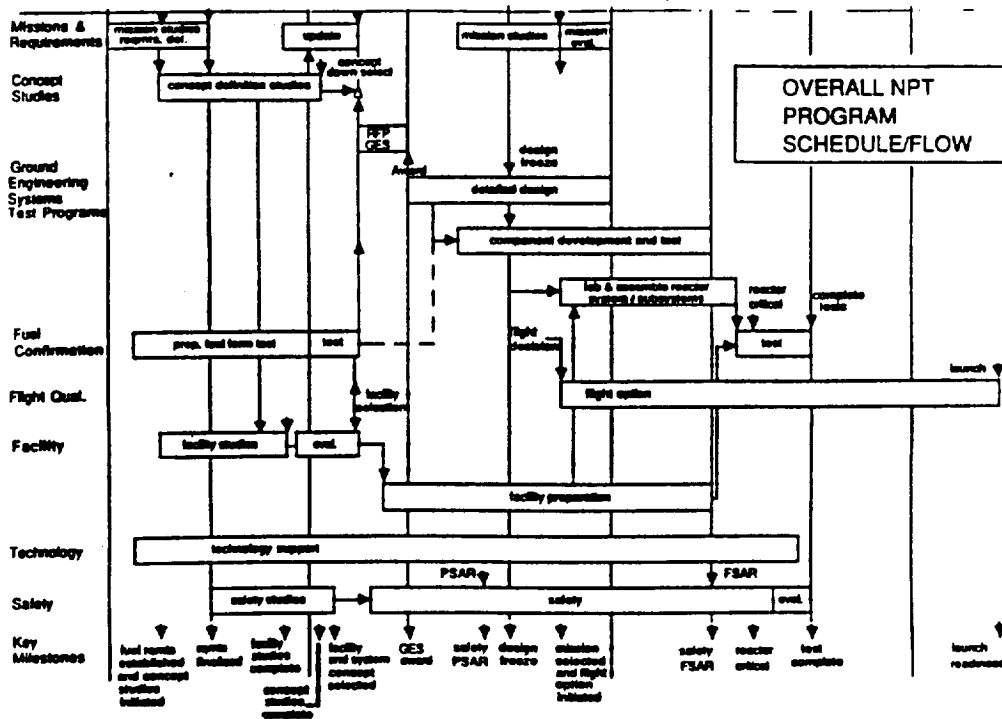
CERMET FUEL PROPULSION GROUND TEST

- A Full System Ground Test is Necessary to Qualify the Cermet Fuel Propulsion System for Flight
- Stringent Safety Precautions and Environmental Release Requirements are Anticipated
- Cermet Fuel Offers a Positive Containment With Essentially Zero Release to Environment
- Ground Test Containment/Confinement May be Less Stringent Than for Alternate Concepts

Figure 22



PROGRAM SCHEDULE AND TASK SUMMARY



3K-7/80.1

Figure 23



CERMET FUEL REACTOR

SAFETY FEATURES

- Cermet Fuel is a High Strength, Rugged Fuel Form Which Can Withstand High Temperatures and Repeated Rapid Thermal Cycles
- Cermet Fuel Offers Positive Fuel Retention With Essentially Zero Fission Product Release to Environment
- Cermet Fuels High Strength Provides for Safe Re-Entry and Burial Configuration in the Event of a Launch Abort Accident
- Cermet Fuel Materials (W, Re) Provide Inherent Safety in Event of Water Immersion Accident

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Figure 24

